Preparedness for responding to a radiological or nuclear attack requires dedicated resources, a sustained vision, and measurable performance requirements.

Health Aspects of a Nuclear or Radiological Attack

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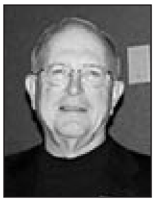

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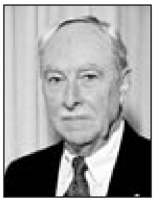

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Since September 11, 2001, the National Council on Radiation Protection and Measurements (NCRP) has produced several publications related to: the detection and interdiction of nuclear and radiological materials and weapons (NCRP, 2003a,b, 2007, 2010a,b); preparation, training, and countermeasures to acts of nuclear or radiological terrorism (NCRP, 2001, 2005a,b, 2009, 2010c,d); and cleanup and restoration of contaminated sites (NCRP, 2010e). Information on these publications is available at *http://NCRPpublications.org*.

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This brief paper provides a summary of key issues facing local, state, and national responders in preparing for and counteracting acts of nuclear or radiological terrorism, including medical management and follow-up care for victims. We also provide a brief look at important issues that remain to be addressed.

A Radiological Attack

As part of the government's preparations for responding to radiological or nuclear attacks by terrorists, National Planning Scenarios have been developed for two types of attack: (1) a radiological-dispersal device (RDD)—a so-called "dirty bomb"; and (2) an improvised nuclear device (IND) (NPS, 2005).

An attack with an RDD is considered the more likely of the two because explosives and radioactive materials from waste, hospitals, and test sources are widely available (Hamilton and Poston, 2004; Medalia, 2002; NPS, 2005; Zimmerman and Loeb, 2004). Radiation exposure from an RDD can be either from an external source (i.e., radioactive contamination) or from internalized radioactive materials inhaled as aerosolized particles or embedded fragments. Pedestrians and vehicles moving through contaminated areas can resuspend and redistribute radioactivity for hours after an explosion thus greatly expanding the contaminated area (NPS, 2005). In addition to radiation exposure, many people would suffer burns and wounds from the explosion.

Because of the large variety of radioactive materials and possible dispersal mechanisms, the specifics of radiation exposure can vary greatly. For example, there could be a non-explosive dispersion of radioactive materials, such as the introduction of radionuclides into a municipal water supply or as contaminants in food. The resulting radiation exposure doses would likely be low, but many people could be affected because recognition of a radiological threat would be delayed until responders arrived with detectors or public health officials noticed radiation-induced symptoms in affected individuals (NCRP, 2001).

An alternative to active dispersal would be a radiological exposure device (RED), that is, a radiation-emitting source hidden in a public space (DHHS, 2010). For example, an RED placed in a heavily frequented area would surreptitiously expose the civilian population to radiation. A carefully disguised RED on a train or in a shopping mall could expose large numbers of people before the source was discovered.

A Nuclear Attack

Although detonation of an IND is considered less likely than an attack using an RDD or RED, it would be the most devastating scenario. A nuclear weapon in terrorist hands might range from a 1-kiloton (kT) device the size of a large backpack to a 10- to 20-kT device analogous in power to the nuclear weapons used in World War II.

Detonation of a nuclear device would lead to prompt exposures to both gamma and neutron radiation. The ratio of neutron to gamma radiation would vary with weapon yield, distance from the blast, and shielding.

> *Radioactive materials for a "dirty bomb" are widely available.*

With a surface-level burst, soil and water would be vaporized by the heat of the explosion, activated by neutrons, and dispersed as fallout. The distribution of the fallout would depend on the height of the burst and the specific meteorological conditions. External radiation from fallout is predominantly from gamma and beta radiation. Doses from fallout would likely be lower than prompt doses and could be delayed because of the time required for the radiation to reach downwind locations (NCRP, 2001). There are also hazards from internalized radioactive material. A 10-kT nuclear device would also cause moderate to severe blast damage to structures within a mile of the detonation.

Responding to Terrorist Incidents

The ability of federal, state, and local response authorities to plan and prepare for managing terrorist incidents is complicated by limited resources (e.g., funding, personnel, and equipment). In addition, these organizations are already called upon to respond to a great many incidents and crises, and terrorist incidents are generally agreed to be low-probability, though high-consequence, events.

On the one hand, not planning a response to terrorist incidents would leave communities vulnerable and totally unprepared. On the other hand, adequate planning without dedicated resources and a sustained vision can have an adverse effect on the quality of response.

The easiest way to ensure preparedness for a terrorist incident is for government authorities to make it a high priority, which would entail dedicated budgets and measurable performance requirements. Response planners would then be able to staff and gather resources at appropriate levels.

Without government support, even if an organization has dedicated program requirements for terrorism preparedness, the funding would have to be taken from another part of its asset base. Thus preparation would be a zero sum game for them; they would be faced with meeting extra job requirements using the same resource base.

Response communities must have ongoing, dedicated funding to build sustainable competence and resources.

Because the recent financial crisis has forced cutbacks in response personnel and critical programs, the situation today is even worse than it was several years ago. With no guidance available, response organizations must manage as best they can with whatever resources they can muster.

Clearly, for preparation and training for terrorist incidents to become a reality, we must have a paradigm shift in the thinking of communities and organizations that support emergency responders. These organizations, which include local, state, and federal offices with preparedness assets, such as the U.S. Department of Homeland Security and professional organizations (e.g., NCRP) and societies (e.g., Health Physics Society), must help response communities articulate a sustained vision of terrorism response preparedness.

Even if the state of preparedness is not ideal, the vision should be translated into specific requirements. For example, a requirement should be established that first-on-scene responder vehicles be equipped with specialized chemical, biological, radiological, and nuclear (CBRN) detection equipment so that suspected threat agents can be detected within a specified number of minutes after they arrive. CRBN requirements should also be established for medical triage and treatment capabilities, population monitoring, decontamination, and so on.

The requirements should be developed by a process that engages stakeholders at all levels and should be tailored to meet the needs of individual communities. The requirements should include: the number of personnel required to perform necessary functions; training requirements; equipment needs; desired end states; and other detailed information. Planners should leverage multi-use job functions, equipment, and training whenever possible.

Preparation and training do not have to be the same for every community. The Urban Area Security Initiative (UASI) has identified cities at risk to encourage regional preparedness. The UASI model could also be used to prioritize regions at greatest risk, and those communities should then insist that terrorism preparedness and training be made a priority.

The federal government provides grants to response communities through competitive processes to bolster preparedness for terrorism response. As a result, there are storage rooms filled with necessary equipment, but many responders are not adequately trained to use or maintain it. Response communities do not benefit much from grants that provide one-time funding to build competence that is not sustainable. The responder's mantra, "You lose what you don't use," applies to every aspect of response preparedness. Therefore, future grant programs must provide measurable, sustainable approaches to preparedness.

Unfortunately, a well organized government program that provides an ideal pathway to response preparedness is not likely to emerge soon. Nevertheless, numerous local and state communities around the nation have shown tremendous ingenuity when it comes to terrorism response preparedness. These communities have realized that building competency through job function would be ideal, but given the low-probability, high-consequence nature of a terrorist attack, training and routine exercises will be necessary to refine and maintain the skills necessary for an effective response.

To advance preparedness and training programs, communities should first assess their ideal end states according to the threats they face. They should then seek support from all levels of government and from all available funding sources. If requirements have not been developed or are not available, they must establish them and develop a strategic plan to describe how and when the requirements will be met and how they will work.

The community will then have to implement the strategic plan step by step. Training, exercises, and equipment maintenance should be integrated into a comprehensive plan for sustaining the state of preparedness. The community must regularly assess its progress and ensure that the resources for supporting preparedness remain available.

Potential Health Effects of a Nuclear Incident

Health effects are most likely to result from localized or whole-body exposures to radiation rather than from the internal or external deposition of radionuclides (contamination). Localized, deep exposure to radiation caused by handling highly radioactive sources may result in a localized radiation burn manifested initially by reddening of the skin (erythema) and later by desquamation, blistering, and, potentially, necrosis.

Because the dose rate drops rapidly with distance from the source, systemic manifestations are not as severe as local injuries. Erythema in the first hours or days indicates an acute skin dose of > 2 gray[1] (Gy). Dry or moist desquamation occurs at doses of more than 10 Gy; doses of more than 15 Gy can result in permanent injury, including atrophy, telangiectasia (dilated superficial blood vessels), and ulceration.

Large acute doses (more than about 2 Gy) of whole-body penetrating radiation can result in various forms of acute radiation syndrome (ARS), which becomes manifest over a period of hours to weeks. In the first few hours, the prodromal phase of ARS may include nausea, vomiting, fever, and diarrhea. In the following weeks, at doses of > 2 Gy, there may be mild bone marrow depression; with doses of 10 to 30 Gy, there will be severe bone marrow depression and damage to the gastrointestinal mucosa resulting in infection, sepsis, and bleeding.

At acute doses of more than 30 Gy, changes will be apparent sooner (hours to days) related to injury to the cardiovascular and central nervous systems. Patients exposed to acute doses of > 5 Gy to the lens of the eye are likely to develop some degree of cataract within a few years.

Internal contamination can occur transdermally or through inhalation, ingestion, or wounds. For the most part, acute health effects will be minimal, although an IND or reactor accident would release radioiodine that could result in hypothyroidism or late thyroid nodules or cancer. External contamination, particularly from intense high-energy, beta-emitting radionuclides, can result in significant widespread skin injuries, which then become portals for infection. If present with ARS, widespread skin injury significantly increases mortality.

In the event of a ground-level detonation of an IND, exposure to fallout in the first few hours could cause beta burns but also enough penetrating radiation to cause ARS and lethality. Any combination of thermal or traumatic injuries with radiation increases complications and mortality.

Late health effects are predominantly radiation-induced carcinogenesis. Radiation can induce many (but not all) types of cancer and leukemia, which often take years, even decades to develop. The risk of fatal cancer in acutely exposed populations is on the order of 5 percent per sievert.[2] There is little evidence of hereditary effects in humans.

Any combination of radiation with thermal or traumatic injuries increases the likelihood of complications and mortality.

Prompt Treatment and Long-Term Monitoring

Victims of acute radiation-related events will require prompt diagnosis and treatment of emergency medical and surgical conditions, as well as of conditions related to possible radiation exposure. Traditional medical and trauma criteria should be used for triage. Radiation doses to patients can be estimated by rapid automated biodosimetry and clinical parameters, such as the history and timing of symptom complexes, the time to emesis, lymphocyte depletion kinetics, chromosomal damage, and multi-parameter biochemical tests.

Acute high-level radiation exposure should generally be treated medically as involving multi-organ failure (MOF). Radiation-induced multi-organ dysfunction

[1] Gray (Gy) is the special name for the SI unit of absorbed dose (1 Gy = 1 J kg⁻).

[2] Sievert (Sv) is the special name for the SI unit of equivalent dose and effective dose (1 Sv = 1 J kg⁻).

(MOD) and MOF are defined as progressive dysfunction of two or more organ systems as a result of radiation damage to cells and tissues over time. Radiation-associated MOD appears to develop partly as a consequence of systemic inflammatory response syndrome and partly as a consequence of radiation-induced loss of functional cell mass in vital organs (for more detail see Fliedner et al., 2009). The Strategic National Stockpile Radiation Working Group recently issued recommendations for medical management of ARS (Waselenko et. al., 2004), and a website on medical management (*http://www.remm.nlm.gov/*) provides guidelines for the management of acute radiation injury (Bader et al., 2008).

An IND incident would result in victims with both radiation injury and conventional trauma. In a recent report on the scientific aspects of combined injuries (radiation + burns or trauma), the authors concluded that two (or more) injuries that are sublethal or minimally lethal when they occur individually act synergistically with radiation injury, resulting in higher mortality (DiCarlo et al., 2008).

Proper supportive care of ARS can significantly prolong survival. The lethal dose for survival of 50 percent of contaminated persons for 60 days ($LD_{50/60}$) is approximately 3 to 4 Gy in persons managed without supportive care. The $LD_{50/60}$ can be increased to 6 to 7 Gy with antibiotics and transfusion support. The lethal dose appears to be even higher with early administration of hematopoietic colony stimulating factors.

Only about half of the general public understands the differences between a nuclear device and a "dirty bomb."

Patients most amenable to treatment will have received doses of 2 to 6 Gy. If there are people who have been subject to doses of more than 6 to 8 Gy, and they also have significant blast or thermal injuries, the combined injuries will preclude survival. For patients with few or no other injuries, however, many authorities would consider stem cell transplants (peripheral or cord-blood) for victims irradiated in this dose range.

It is common practice to distinguish late physiological effects from early effects of radiation exposure. Deterministic effects are acute and typically show a sigmoid dose-response curve; the severity of harm from the radiation exposure increases with dose. Effects are non-neoplastic and are rather promptly expressed in exposed individuals. In contrast, late stochastic effects (i.e., non-threshold effects) represent a probabilistic tissue response to radiation exposure. Stochastic effects are generally expressed later.

Follow-up medical care of an irradiated individual will, therefore, focus on late effects, most significantly the detection of cancer. In addition, late psychological effects from radiation exposure should always be considered in continuing medical surveillance. For patients with relatively low-dose exposures, the long-term psychological trauma may be more medically significant than radiation-induced organ damage.

Issues to be Addressed

The number of key issues remaining to be resolved is much greater than the number of issues considered to date by NCRP or other expert groups. Several important issues have received little or no consideration:

- retaining proficiencies in responder communities; gaps in the training of these individuals; and training new responders
- maintaining equipment and supplies in a state of readiness over long periods of time
- training for responding to attacks with weapons of mass destruction (WMD) as opposed to "dirty bombs"
- ensuring the coordination of all responder organizations at the local, state, and national levels
- addressing late-phase issues after a nuclear or radiological incident, such as reentry, reoccupancy, and recovery of the affected area
- communications with the public before, during, and after an incident
- dealing with psychological impacts and restoring public trust.

Communications

Effective communication prior to an incident, during an incident, and after an incident has been brought under control will be extremely important. Decision makers must issue directives to the public with recommendations for certain areas based on the size and dimensions of the incident. This will require that the general public be able to understand the information and respond appropriately.

For example, many people still to do not understand the term "shelter-in-place," and only about half of the general public understands the difference between a WMD (e.g., an IND) and a "dirty bomb." Thus significant efforts, beginning now, should be made to "educate" the public. These challenges have been addressed by nuclear utilities in the United States as part of their emergency planning, and local, state, and federal officials could learn a great deal from their efforts. So far, however, useful, readily understandable information has not been widely distributed on a national scale.

Late-Phase Activities

To date, efforts have focused mostly on early-phase responses to a terrorist incident. Few have considered the reentry, reoccupancy, or recovery issues. Sullivan et al. (2008), who have considered dose assessments to guide decisions in the event of an RDD incident, emphasize the need for a consensus approach to cleanup and recovery efforts. NCRP agrees that there must be total stakeholder "buy-in" for late-phase recovery efforts (NCRP, 2001). Chen and Tenforde (2010) have discussed the involvement of stakeholders in planning for the cleanup and restoration of contaminated sites.

If a WMD is detonated in an urban environment, the recovery phase will be just as important as the immediate response phase. To plan for late-phase recovery, careful studies of actions taken in Hiroshima and Nagasaki will be essential. Today, both cities are once again thriving, and their recovery represents a "real-world laboratory" from which lessons can be learned for developing response plans for nuclear or radiological terrorist incidents.

Summary and Conclusions

The goals of radiation protection are to *prevent* the occurrence of clinically significant radiation-induced deterministic effects (e.g., ARS) and to *limit* the risk of stochastic effects (e.g., cancer) to a reasonable level in relation to societal needs, values, benefits gained, and economic factors (NCRP, 1993). However, achieving

TABLE 1 Approximate Acute Death, Acute Symptoms, and Lifetime Fatal Cancer Risk as a Function of Whole-Body Absorbed Doses of Radiation (for Adults)

Short-Term[a] Whole-Body Dose [rad (Gy)]	Acute Death[b] from Radiation without Medical Treatment (%)	Acute Death from Radiation with Medical Treatment (%)	Acute Symptoms (nausea and vomiting within 4 h) (%)	Lifetime Risk of Fatal Cancer without Radiation Exposure (%)	Excess Lifetime Risk of Fatal Cancer Due to Short-Term Radiation Exposure[c] (%)
1 (0.01)	0	0	0	24	0.08
10 (0.1)	0	0	0	24	0.8
50 (0.5)	0	0	0	24	4
100 (1)	<5	0	5 – 30	24	8
150 (1.5)	<5	<5	40	24	12
200 (2)	5	<5	60	24	16
300 (3)	30 – 50	15 – 30	75	24	24[d]
600 (6)	95 – 100	50	100	24	>40[d]
1,000 (10)	100	>90	100	24	>50[d]

[a] Short-term exposure = radiation exposure during the initial response to the incident. The acute effects listed are likely to be reduced by about one-half if radiation exposure occurs over a period of weeks.

[b] Acute deaths are likely to occur 30 to 180 days after exposure; there will be few if any after that time. Estimates are for healthy adults. Individuals with other injuries, and children, will be at greater risk.

[c] Most cancers are not likely to occur until several decades after exposure, although leukemia has a shorter latency period (<10 years).

Source: NCRP, 2005b.

these goals may not be possible in the event of radiological or nuclear terrorism.

Table 1 shows two types of health risks that may result from short-term, high-level, whole-body radiation exposure that could occur as a result of a terrorist incident involving an IND: (1) acute deaths from injury to organs and tissues (e.g., bone marrow); and (2) increased risk of solid cancers (typically 10 to 40 years after exposure) and leukemia (less than 10 years after exposure).

Immediate and sustained investments by the U.S. government in infrastructure development (e.g., radiation detectors), education, training, communication, and medical countermeasures will be essential to ensuring the nation's ability to address the immediate and long-term health effects of a radiological or nuclear incident.

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